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A Survey of the Host Galaxies of Gamma-Ray Bursts[1]

Stephen Holland*

*Department of Physics
University of Notre Dame
Notre Dame, IN 4655–5670
U. S. A.

Abstract. We used 45 *HST*/STIS orbits in Cycle 9 to obtain deep images of the host galaxies of eleven gamma-ray bursts. Our goals are to study the morphologies of the host galaxies, to obtain precise locations of gamma-ray bursts within their host galaxies, and to determine star-formation rates in the hosts. We present preliminary results for GRB 980425/SN1998bw, GRB 980613, and GRB 9809703.

INTRODUCTION

We have obtained deep images of the host galaxies of eleven gamma-ray bursts (GRBs) using the Space Telescope Imaging Spectrograph (STIS) aboard the *Hubble Space Telescope* (*HST*). Data was taken using the 50CCD (clear) and F28X50LP (long pass) apertures, which peak at approximately the V and R photometric bands. Each image was taken more than one year after the burst to study the overall morphology, and the small-scale structure of each host, without contamination from the GRB's optical afterglow (OA). Our goals are to classify the morphologies of the host galaxies, identify substructure in each host, and to probe the star-formation rate at high redshifts. Combining ground-based observations of the OAs with our *HST* data allows us to determine precise positions for each GRB relative to substructure (such as bulges, spiral arms, HII regions, star-forming regions, etc.) in the host. The images will be used to compare the distribution of host morphologies to galaxies in the Hubble Deep Fields, and to search for correlations between specific types of substructure and GRBs. Morphological information, and the spectral energy distribution, will allow us estimate overall star-formation rates and the amount of dust present. We have waived all proprietary rights to this data. The reduced data are available at `http://www.ifa.au.dk/~hst/grb_hosts/index.html`. This paper presents some preliminary results from this project.

[1)] Based on observations with the NASA/ESA *Hubble Space Telescope*, obtained at the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc. under NASA contract No. NAS5–26555.

GRB 980425

There is growing evidence that GRBs are related to the deaths of massive stars. GRB 980425 and the Type Ib/c supernova SN1998bw coincided in time and position on the sky [5], GRB 990123 coincided with a star-forming region [8], and there is evidence for a GRB/SN connection for eleven other GRBs (see [10] for a list).

The host galaxy of GRB 980425 is ESO 184−G82, a sub-luminous, barred spiral (SBc) galaxy that is in a stage of strong star formation. The galaxy lies at a distance of 36.64 Mpc, making GRB 980425 the nearest known GRB. The host has a size, structure, luminosity, and star formation rate similar to those of the Large Magellanic Cloud. ESO 184−G82 appears to be a member of a compact group with the nearest neighbour located at a projected distance of only 11.9 kpc and shows indications of being morphologically disturbed. Therefore, this galaxy may be undergoing interaction-induced star formation.

SN1998bw/GRB 980425 occurred in an HII region approximately 300 pc in diameter. There are several bright, young stars within a projected distance of approximately 100 pc of the supernova/GRB (Fig. 1).

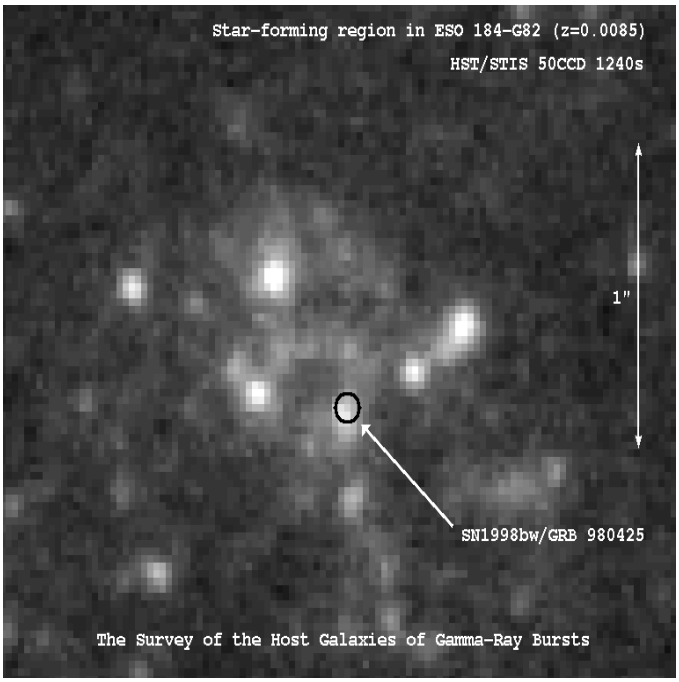

FIGURE 1. This Figure shows our *HST*/STIS 50CCD image of the star-forming region where GRB 980425/SN1998bw occurred. The plate scale for all the *HST*/STIS images presented in this paper is 0.″0254/pixel. The circle shows the location of the supernova/GRB. Three of the stars in the star-forming region have colours that are consistent with red giants while three stars have blue colours that are consistent with their being massive main-sequence stars [4].

GRB 980613

GRB 980613 occurred near the edge of a compact blue star-forming region which may be part of a larger structure (Fig. 2). The morphology of the host is chaotic, and we find no evidence for spiral structure, or faint substructure connecting the various components. We find a star-formation rate of $\approx 3\mathcal{M}_{\odot}\mathrm{yr}^{-1}$ assuming no extinction in the host galaxy. The rest-frame B-band luminosity is $L_B \approx (0.2 \pm 0.1)L_B^*$ where L_B^* is the luminosity of a typical galaxy at a redshift of $z \approx 1$. The specific star-formation rate per unit blue luminosity is $\approx 20\ \mathcal{M}_{\odot}\mathrm{yr}^{-1}{L_B^*}^{-1}$, the highest value of any known GRB host galaxy [7].

Djorgovski et al. [3] suggested that the host is a set of interacting galaxies. If this is the case then the lack of tidal features suggests that the system has only recently interacted. Alternatively, the colour and morphology of the host are similar to what is seen in low surface brightness (LSB) galaxies. However, the host galaxy shows strong nuclear activity. This is unlike LSB galaxies, which tend not to exhibit nuclear activity, although some of the larger LSB disk galaxies do show nuclear activity [2] similar to that seen in the host of GRB 980613. The large specific star-formation rate is unusual for an LSB. However, most of the star formation occurs in the nucleus and is not distributed through-out the galaxy. Therefore, the host may be an LSB galaxy where star formation is in the process of turning on.

GRB 980703

The host of GRB 980703 is a bright galaxy with an "egg-shaped" morphology that resembles a lop-sided barred spiral (Fig. 3a). We estimate a star-formation rate of 8–$13\mathcal{M}_{\odot}\mathrm{yr}^{-1}$ using Eq. 2 of [12] and assuming that there is no extinction in the host galaxy. The rest-frame B-band luminosity is $(1.6 \pm 0.4)L_B^*$. Therefore, the star-formation rate per unit luminosity is $\approx 6.5\mathcal{M}_{\odot}\mathrm{yr}^{-1}{L_B^*}^{-1}$, which is similar to the values found for several other GRB host galaxies.

We fit two-dimensional Sersic [16] models to the *HST*/STIS images, after convolving with the appropriate point-spread function [10], and found a half-light radius of $0\farcs13 \pm 0\farcs01$, $n = 1.05 \pm 0.02$ ($n = 4$ corresponds to a de Vaucouleur $R^{1/4}$ profile), and an ellipticity of 0.24 ± 0.02. This is consistent with an exponential disc with a scale radius of $0\farcs21 \pm 0\farcs01$. Fig. 3b shows the host with the best-fitting model subtracted. Except for the central regions the galaxy is well fit by this model. The systematic residuals in the central few pixels suggest that there is substructure in the galaxy. The excess of light on the west side of the galaxy may be a spiral arm. The derived half-light radius is much smaller than those seen in local late and early type galaxies [11]. However, the size, colour, and spectrum of the host are similar to those of compact galaxies in the Hubble Deep Field North [13,6].

STAR FORMATION AND HOST MORPHOLOGY

There is evidence that redshifts of GRBs can be determined from the intrinsic properties of the bursts [15,14]. These techniques will allow the distribution of GRBs to be mapped to high redshifts solely from the observed gamma-ray pulse. However, in order to connect the GRB rate with star formation in the early Universe it is important to understand the connection between GRBs and star formation in individual galaxies. Preliminary results from our Cycle 9 observations suggest that long-duration ($T_{90} > 2$ s) GRBs are located in star-forming regions [9,10,7]. This is consistent with the growing evidence that GRBs are produced in the early stages of a supernova explosion. Our data suggests that hosts tend to be sub-luminous with high rates of star-formation per unit luminosity (see Table 1).

Fig. 4 shows images of eight GRB host galaxies. There is no single morphological type for GRB hosts, although most appear to occur in late-type and irregular galaxies (but see [1]). Our preliminary results suggest that the morphologies of GRB host galaxies are no different from other star-forming galaxies at the same redshift.

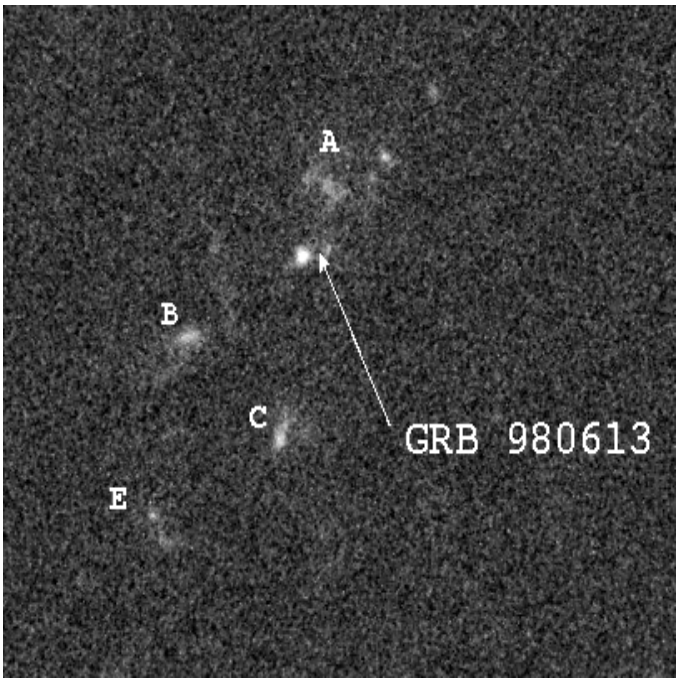

FIGURE 2. This is our STIS 50CCD (clear) image of the environment of GRB 980613. The resolution (i.e., the apparent diameter of a point source) is $0\farcs084$. The field of view is approximately $7\farcs5 \times 7\farcs5$ ($= 60 \times 60$ kpc assuming $(H_0, \Omega_m, \Omega_\Lambda) = (70, 0.3, 0.7)$).

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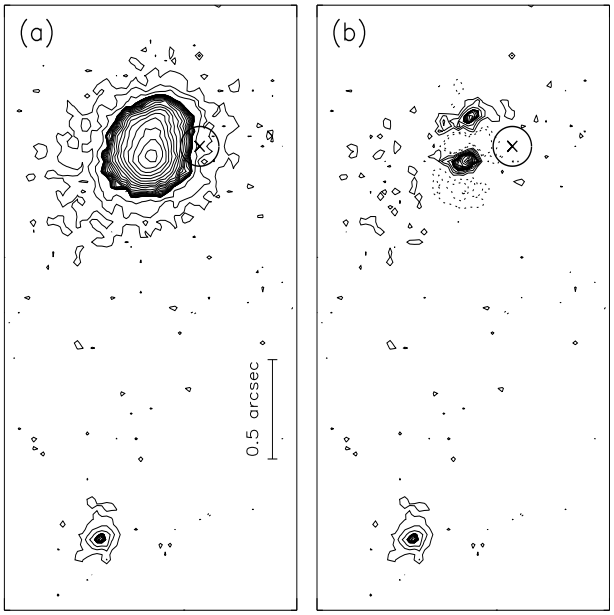

FIGURE 3. a): This Figure shows the *HST*/STIS 50CCD GRB 980703. The outer contours are linear while the inner contours are logarithmic to show the host over a large dynamic range. The location of GRB 980703 is marked with an "X" and our 1σ error circle. **b)**: This Figure shows the host with the best-fitting Sersic [16] model subtracted.

TABLE 1. Specific star-formation rates for several GRB host galaxies.

GRB	z	$R_{\rm host}$	$\mathcal{M}_\odot {\rm yr}^{-1} L_B^{*\,-1}$
970508	0.835	25.20	11.0
980613	1.096	24.56	20.0
980703	0.966	22.57	6.5
990123	1.600	24.07	11.0
990712	0.434	21.91	4.4

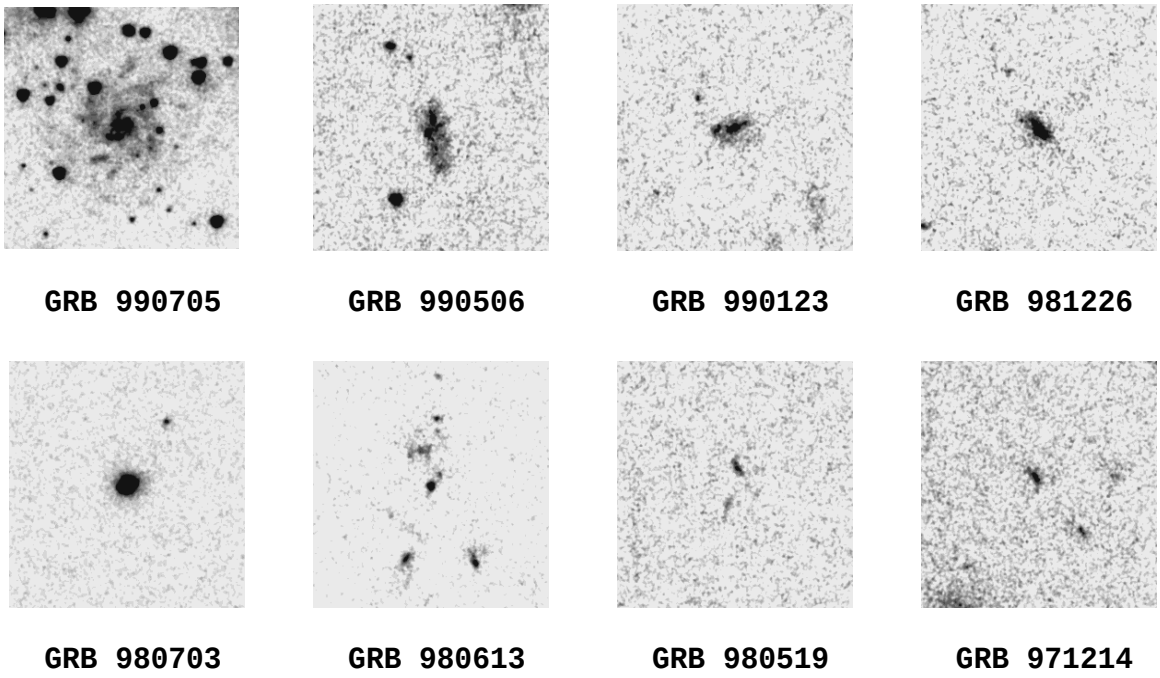

FIGURE 4. This Figure shows *HST*/STIS images of eight host GRB galaxies. Each image is in 50CCD except GRB 990123, which is in F28X50LP. The fields of view are $6\farcs5 \times 6\farcs5$.

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